Proceedings of the International Multiconference on
Computer Science and Information Technology pp. 487–493
ISBN 978-83-60810-14-9
ISSN 1896-7094

Accurate Localization in Short Distance based on Computer Vision for Mobile Sensors

Kwansik Cho, Ha Yoon Song, Jun Park
Department of Computer Engineering, Hongik University, Seoul, Korea
mstr50@gmail.com, hayoon@wow.hongik.ac.kr, jpark@cs.hongik.ac.kr

***Abstract*—In order to maximize the utilization of mobile sensor network, formation of sensor set and localization of each sensor node must be implemented. It is required that localization is one of the most important functionality of mobile sensor nodes. In this paper, we present a technique which improves the relative location of the MSN with a computer vision technology.**

This technique effects only in short distance but only with low price sensors, we achieved precise localization in the resolution of 10 centimeters. The well known perspective-3-point problem have been exploited for the precise short distance localization. By experiment we present an interrelation between angle of camera view and a LED pattern interval. We measures the distance of the counterpart vehicle and vehicles shares distance information of obstacle and the relative vehicles with possible cooperation of vehicles. The angle of a vehicle can be identified by digital compass. Finally, with a share of location information we can achieve localization of mobile sensor nodes with high accuracy.

I. INTRODUCTION

THIS research is regarding short distance localization with use of computer vision technology under Mobile Sensor Network (MSN) environment. In order to maximize the utilization of mobile sensor network, formation of sensor set and localization of each sensor node must be implemented.

We built several Mobile Sensor Vehicles (MSVs) as mobile sensor nodes for a mobile sensor network. Each MSV can identify locations of companion MSV and can share such information in order to achieve accurate localization of whole MSVs. We used a micro camera as a visual sensor of MSV. The result of localization can be presented on maps based on grid or topology. We believe this research can be applied formation of UAV (Unmanned aerial vehicle), a formation for a deep-sea fishing vessel and other related area.

This paper is structured as follows. In section II we will show related problems and possible solutions of localization. Section III discusses retailed experiment procedure for localization and section IV will show the result of localization. The final section V will conclude this paper with discussions of possible future research.

II. RESEARCH BACKGROUND

There have been variety forms of Mobile Sensor Nodes (MSN) which utilizes various techniques of localizations such as RSSI, GPS, Raider, Laser, Camera, and so on [1] [2]. One of the most prominent one, an RSSI based localization, usually measures radio signal strength and it works well with popular network devices. Moreover, an 802.11 device based software approach can be realize easily. However, RSSI method is prone to be fragile with a presence of obstacles or so which will diminish or attenuate radio signal strength. In a short distance, RSSI signals usually is too high that nullify accurate localization thus it is good for long distance, low accurate localization.

For medium distance, a trajectory based approach is a useful one. Usually mobility is recorded and the accumulated records are used to calculate current location of mobile sensor nodes. However, also traveling errors are accumulated as traveling distance increased.

In this paper we will discuss about short distance, high accurate localization. It is based on computer vision and of course it has limitations of distance with visibility.

We combined these three levels of localization technique and will focus on computer vision based one. For the purpose of experiments, we designed and implemented Mobile Sensor Vehicle (MSV) which has all three levels of localization features aforementioned as shown in [3].

In this section, we will discuss about related problem.

A. Identification of Colleague MSVs as a base for localization

Localization is required for MSN in order to maximize its usefulness. However, a single MSV cannot locate its location precisely. The ultimate localization can only be done with the cooperation of nodes in MSN.

The first requirement for localization is to identify the location of colleague MSV as a base point. For this purpose, we prepared three facilities for each MSV. Each MSV can estimate its location by trajectory trail. Moreover, each MSV can identify other colleague MSV with their infrared LED signal. In addition, this location information can be communicated by wireless network device equipped with each MSV.

Of course, a camera or a set of cameras are installed on an MSV in order to identify colleague MSVs. This set of cameras have infrared filters in order to diminish the effect of extra light noise in operating environment.

B. Location Determination Problem

With a set of camera, the required information for localization is collected from the view of cameras. For example, an infrared LED light can be a parameter to calculate the colleague's location. In this research, we applied two previous results. The first one is Sample Consensus(RANSAC) Method [4] and the second one is PnP Method [5] [6].

This work was supported by 2007 Hongik University Research Fund.

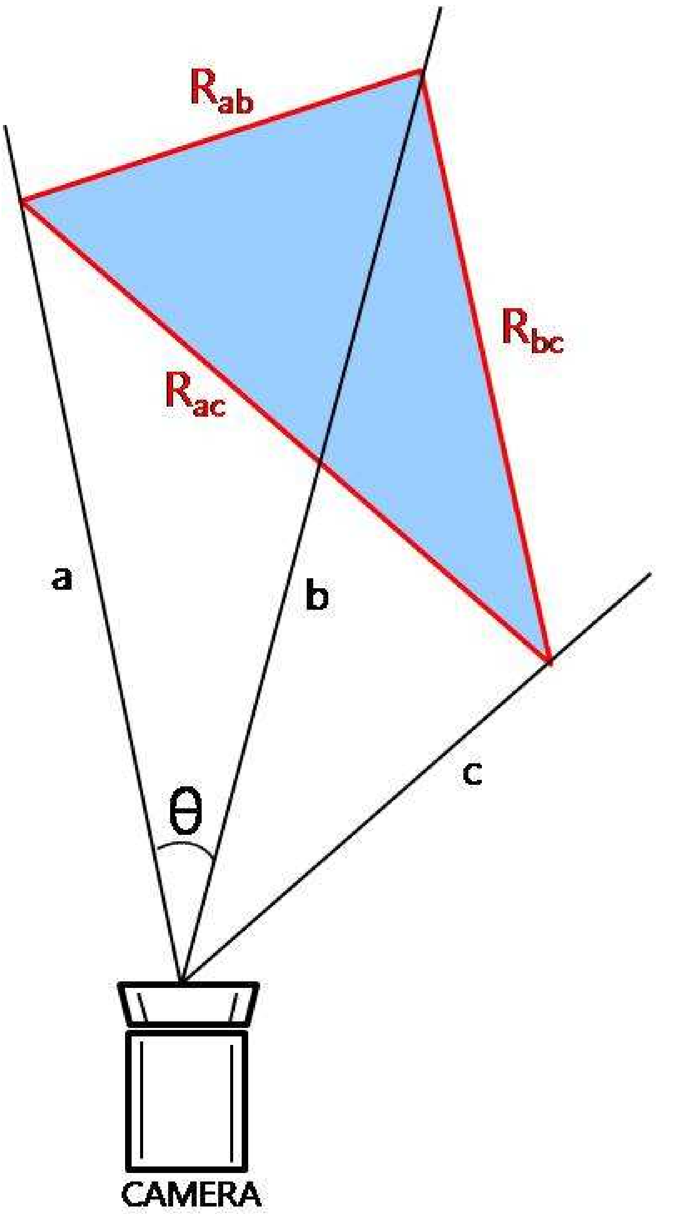

Fig. 1. Calculation of distance from Camera Lens to Vertex of triangle ABC

For RANSAC method, because of least square method, there is no possibility of wrong computation with gross error value. This is the major reason why we applied RANSAC method. In order to solve the problem of converting 3-dimensional view to 2-dimensional camera image, which has lost distance problem, we applied perspective-3-point (P3P) problem.

Figure 1 shows the basic principle of P3P problem. The gray triangle is composed by infrared LED installed on each MSV. Points A, B, C stand for each infrared LEDs and these vertices compose a triangle. The distance R_{ab}, R_{bc}, R_{ac} is known constants.

From figure 1 we can drive the following, very well-known, mathematical equation as shown in equation 1.

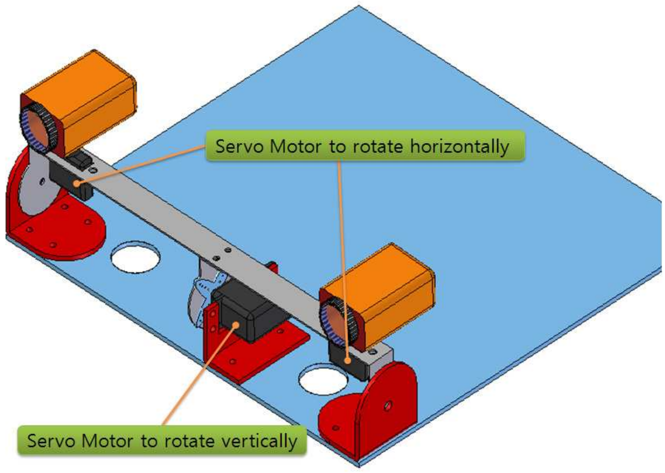

Fig. 2. Stereo Eye System

Fig. 3. Mobile Sensor Vehicle for Experiment

$$\begin{aligned} {R_{ab}}^2 &= a^2 + b^2 - 2ab \cdot cos\theta_{ab} \\ {R_{ac}}^2 &= a^2 + c^2 - 2ac \cdot cos\theta_{ac} \\ {R_{bc}}^2 &= b^2 + c^2 - 2bc \cdot cos\theta_{bc} \end{aligned} \quad (1)$$

The equation 1 is in closed form. The number of solutions from these equations will be up to eight. However, there are up to four positive roots.

With this P3P based method, we can only measure distances between observer and observed. For precise localization, we must identify angle of MSVs as well. Our MSV is equipped with digital compass in order to identify the angle of MSV based on magnetic poles. As predicted, digital compass also has its own error in angle measurement but is tolerable.

Fig. 4. Tracking Program View

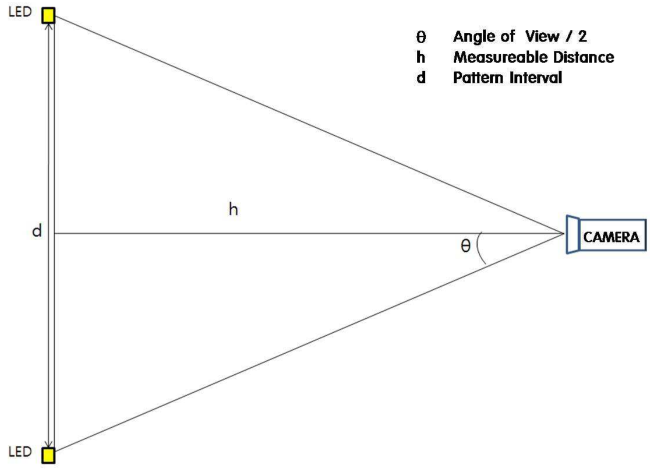

Fig. 5. Correlation of LED pattern interval and measurable minimum distance

TABLE I
IR-LED SPECIFICATIONS

MODEL NO.	Half Angle	Peak Wavelegnth
SI5315-H	±30°	950nm
OPE5685	±22°	850nm
OPE5194WK	±10°	940nm
TLN201	±7°	880nm
EL-1KL5	±5°	940nm

III. Implementation and Experiments

A. Experimental Environment

Each MSV has a set of Infrared LED (IR-LED) in a form of triangle and the length of edges are all 30 centimeters. The IR lights from these LEDs can be viewed by stereo camera system from other colleague MSV. The stereo eye system as shown in figure 2 has two cameras. Three servo motors controls two stereo eyes vertically and horizontally.

The stereo cameras are equipped with IR filters. The front view of MSV for these equipments are as shown in figure 3. Three IR-LEDs forms a triangle and a stereo camera system are also presented.

With fixed length of triangle edges, i.e. interval between IR-LED, is fixed by 30 centimeters. Therefore by using P3P method, the distance between camera and MSVs with IR-LED triangle can be calculated. Embedded software for each MSV has a realtime part for P3P solution. The software also shows the image from stereo camera as a part of P3P solution as shown in figure 4.

The ideal situation starts by estimating the angle between two cameras. Once camera direction is fixed, we can estimate angles between tracked object and cameras, however, MSV can move every direction which causes difficulties to measure that angle. Moreover, if these cameras have pan-tilt functionalities, it is impossible to measure such an angle in real time.

Another method with P3P technique is to assume the distance to the object. The distance to object and the scale of triangle in camera view is proportional inversely thus the size of LED triangle can be a starting point to estimate the distance to obstacles. We decided to standardize the reduced scale of LED triangle in order to estimate distance to objects. The basic concept of this method is depicted in figure 5. We will discuss this figure in the subsection III-C in detail.

This approach has limits of camera visibility, i.e. objects beyond visibility cannot be identified. However, two other localization methods are already prepared for beyond sight localization as described in II. In addition with the help of digital compass, we can measure the direction of each MSV. The combination of this information can achieve short distance accuracy for localization.

B. Preliminary Experiment

We conduct preliminary experiment in order to choose optimal device for computer vision based localization. The first purpose of this experiment is to select the best LED in order to increase the range of localization. Our past result showed 250 centimeter of localization range however our aim is to enlarge the range to 400 centimeters or farther.

We choose five infrared light emitting diodes with typical characteristics. We first concentrated on the visible angle of LED lights since we assumed wider visible angle guarantees the clearer identification of LED light and more precise localization.

Table I shows the specifications of various IR-LEDs with visible angle and peak wavelength. The major reason why we choose those IR-LEDs are as follows:

- Smaller half angle of LED enables long distance tracking however increase invisibility from the side.
- Larger half angle of LED enables tracking from the side however decrease tracking distance.

With infrared filter equipped cameras we planned experiments to evaluate the LEDs for vision based localization. Table II show the result of visible distance and visibility of IR-LEDs. Twelve experiments have been made and average

TABLE II
IR-LED VISIBILITY EXPERIMENTS

MODEL NO.	Max Length	Visible Angle	Visibility
SI5315-H	500cm	$\pm 60°$	Stable
OPE5685	490cm	$\pm 45°$	Somewhat Unstable
OPE5194WK	520cm	$\pm 35°$	Most Stable
TLN201	510cm	$\pm 20°$	Unstable
EL-1KL5	450cm	$\pm 10°$	Indiscriminable

values are shown. From the specifications of IR-LEDs, 5 volts DC voltage is supplied for the experiment.

Among five IR-LEDs, two showed stable visibility and acceptable visibility distance. Between these two candidates, we finally choose the best LED of MODEL NO.SI5313-H since it has the widest half angle as well with reasonable visibility distance.

C. Main Experiments

Figure 5 shows the relationship between LED triangle size (d) and distance from camera to LED triangle (h). The relation between d and h can be directly drawn from the following equation 2

$$\begin{aligned} \tan\theta &= \frac{d}{2h} \\ \theta &= \arctan\frac{d}{2h} \end{aligned} \tag{2}$$

Most of cameras has angle of view in $54° \sim 60°$. Since we used camera with angle of view in $60°$, from the equation 2 we can solve ratio about $h : d = 1 : 1.08$. The actual value of d is 30 centimeter for our experiment.

Thus we can summarize the following:

- High angle of view camera can increase minimum measure distance.
- With narrow LED pattern interval, we can decrease actual distance h but practically meaningless.
- With wider LED pattern interval, we can increase actual distance but dependent on MSV size.

From the experiments, we can identify the vision based localization is effective within the range from 30 centimeters to 520 centimeters with our LogiTech CAM camera. The 30 centimeter lower bound is due to the 30 centimeter interval of LED triangle edges. The 520 centimeter upper bound is due to the visible sight capability of LogiTech CAM camera. Thus 520 centimeter would be a maximum distance of computer vision based localization. However it is still meaningful since we can achieve very high accuracy in localization with these cheap, low grade cameras. The other idea for more localization distance is to use cameras with higher resolution.

From our experiments, we identified the correlation between actual distance from camera to colleague MSV and size of

TABLE III
CORRELATION OF ACTUAL DISTANCE (h) AND RELATIVE SIZE OF LED TRIANGLE

A Regular Triangle (30cm) LED Pattern	
Distance (Cm)	Relative Size Calculated by P3P
70	95.20465
80	84.94255
90	76.69515
100	70.98945
110	66.14175
120	63.67415
130	60.56855
140	57.90765
150	54.40745
160	51.12315
170	49.34895
180	47.84185
190	45.20355
200	43.00485
210	41.95535
220	39.15445
230	37.31475
240	36.35485
250	35.09785
260	34.46155
270	33.87925
280	32.94845
290	31.01745
300	30.20645
310	29.77155
320	28.12365
330	27.65485
340	26.37745
350	25.54655
360	24.78645
370	24.57855
380	23.54155
390	22.78955
400	22.57515
410	22.54655
420	21.78945
430	21.89485
440	20.79875
450	20.42085
460	19.88265
470	19.07455
480	18.78955
490	18.77985
500	17.57515
510	17.54655
520	16.82315

LED triangles in camera view. Table III shows correlations between actual distance and triangle size in camera view. The results in table III can be translated into graphical form as shown in figure 6.

From figure 6 the result shows the fluctuation of results with more than 430 centimeters which makes localization unstable. For applications which require the error range of 20 centimeters, we can use the results to 520 centimeters. Since our aim is to keep localization errors within the range of 10 centimeters, we decided to discard results more than 430 centimeters.

IV. Experimental Result

From our experiment in the previous subsections we will provide the final result of computer vision based localization in this subsection.

Table IV shows the final result. Figure 7 shows graphical version of table IV.

Apart from the results in previous section, these table and figure shows actual distance up to 420 centimeters. From figure 6 we can observe errors in calculated values of P3P for more than 420 centimeter distance. These errors is due to the resolution limit of CAM camera which is 640×480. Even a small noise can vary actual distance of ten centimeters in the distance more than 420 centimeters.

Thus we conclude the accurate localization by computer vision can be done in the range of 70 centimeters to 420 centimeters with our camera equipments.

For the localization in more than 420 centimeters, localization based on MSV trajectory tracking will be effective. In addition, for the localization in more than 30 meters, localization based on RSSI will be effective [3].

V. Conclusion and Future Research

We built mobile sensor vehicle as nodes for mobile sensor network. Our mobile sensor nodes has capabilities in multilevel localization. In this paper we discussed regarding computer vision based localization.

We can achieve very precise and short distance localization with the help of computer vision technology.

Within the distance of 420 centimeters, we can identify the location of each mobile sensor nodes in a resolution of 10 centimeters. And within the distance of 520 centimeters, we still have the possibility of localization in a resolution of 20 centimeters.

However our experiment has several limitations due to the resolution of cameras and the vertices distance of LED triangle. Since the vertices distance of LED triangle is limited by the chassis size of MSV, we cannot extend the distance more than current configuration.

Therefore for future researches, we plan to upgrade cameras and the angle of view for cameras as well for longer localization distance. With this better sensors and calibration of sensors we expect that we can extend the localization distance up to 1,000 centimeters.

TABLE IV
Calculated Distance from Measured Relative Distance

Relative Distance Measured	Actual Distance Assumed (Cm)
99.99999 ∼ 95.20465	70
95.20464 ∼ 84.94255	80
84.94254 ∼ 76.69515	90
76.69514 ∼ 70.98945	100
70.98944 ∼ 66.14175	110
66.14174 ∼ 63.67415	120
63.67414 ∼ 60.56855	130
60.56854 ∼ 57.90765	140
57.90764 ∼ 54.40745	150
54.40744 ∼ 51.12315	160
51.12314 ∼ 49.34895	170
49.34894 ∼ 47.84185	180
47.84184 ∼ 45.20355	190
45.20354 ∼ 43.00485	200
43.00484 ∼ 41.95535	210
41.95534 ∼ 39.15445	220
39.15444 ∼ 37.31475	230
37.31474 ∼ 36.35485	240
36.35484 ∼ 35.09785	250
35.09784 ∼ 34.46155	260
34.46154 ∼ 33.87925	270
33.87924 ∼ 32.94845	280
32.94844 ∼ 31.01745	290
31.01744 ∼ 30.20645	300
30.20644 ∼ 29.77155	310
29.77154 ∼ 28.12365	320
28.12364 ∼ 27.65485	330
27.65484 ∼ 26.37745	340
26.37744 ∼ 25.54655	350
25.54654 ∼ 24.78645	360
24.78644 ∼ 24.57855	370
24.57854 ∼ 23.54155	380
23.54154 ∼ 22.78955	390
22.78954 ∼ 22.57515	400
22.57514 ∼ 22.54655	410
22.54654 ∼ 21.78945	420

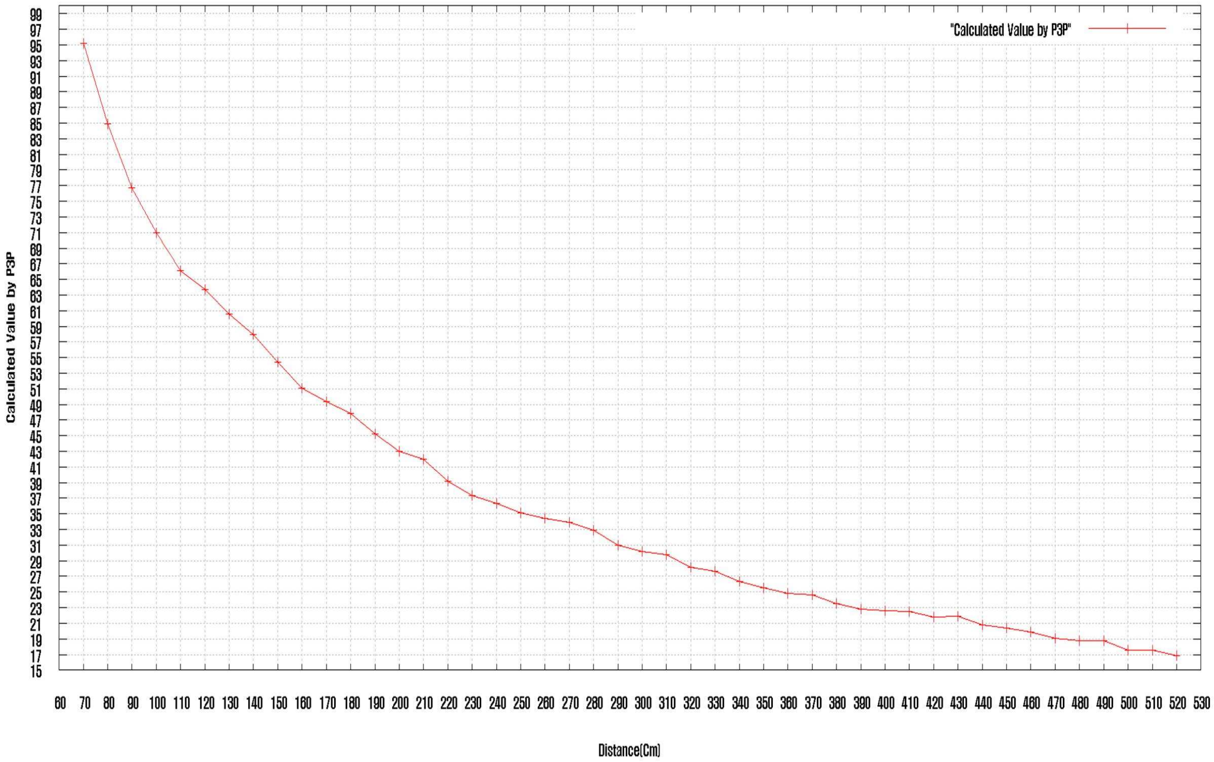

Fig. 6. Relative size of triangle calculated by P3P on actual distance

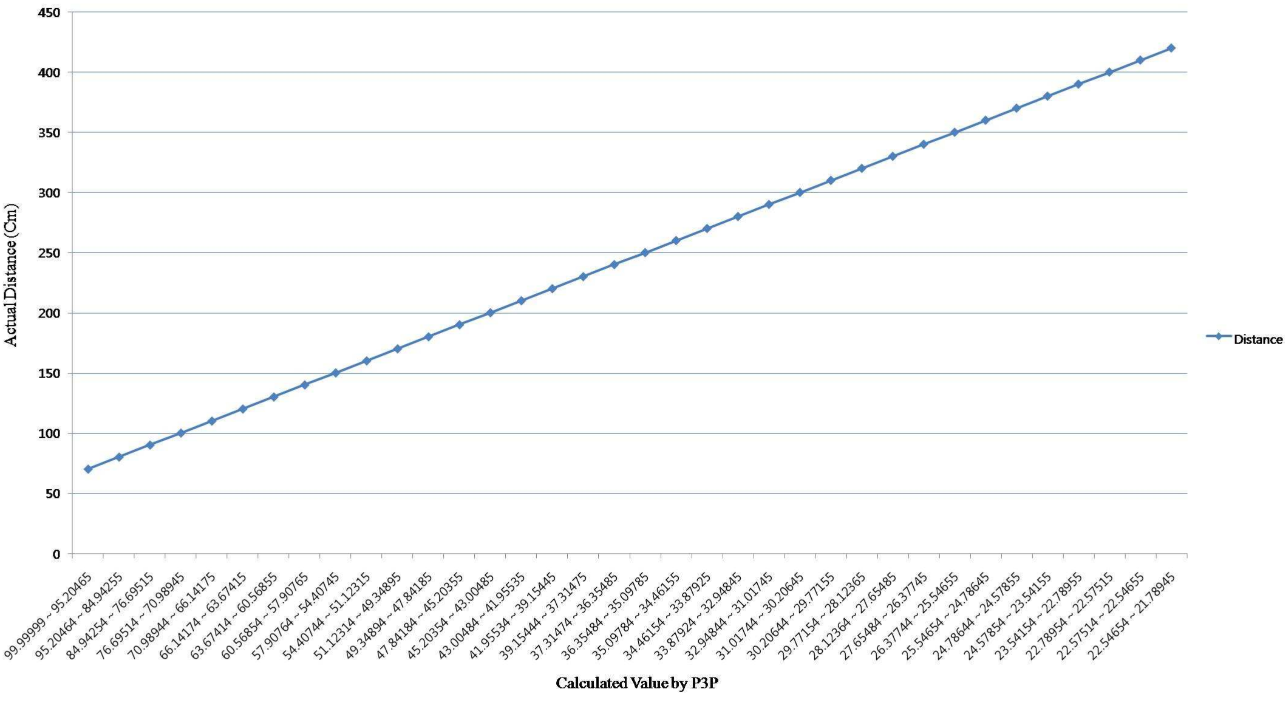

Fig. 7. Actual distance calculated from measured relative distance

We believe we showed an example of high accuracy localization and this research will help researchers for such applications in a field of mobile sensor network as well as robotics.

With these precise localization methods, a sensor formation technique will be a feasible one.

REFERENCES

[1] J.-S. Gutmann, W. Burgard, D. Fox, K. Konolige, "An Experimental Comparion of Localization Method," IROS, 1998.

[2] J.-S. Gutmann, C. Schlege, AMOS, "Comparison of Scan Matching approaches for self-Localization in indoor Environments," EUROBOT, 1996.

[3] Jae Young Park, Ha Yoon Song, "Multilevel Localization for Mobile Sensor Network Platforms," International Workshop on Real Time Software (RTS'08), *International Multiconference on Computer Science and Information Technology, 20–22 October 2008, Wisla, Poland,* IEEE Press.

[4] M. A. Fischler, R. C. Bolles, "Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography," Comm. of the ACM, Vol. 24, pp. 381–395, 1981.

[5] Xiao Shan Gao and Xiao Roing Hou and Jianliang Tang and Hang?Fei Cheng, "Complete Solution Classification for the Perspective Three Point Problem," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 25, August 2003.

[6] Haralick, R.M and Lee, D and Ottenburg, K and Nolle, M, "Analysis and Solutions of The Three Point Perspective Pose Estimation Problem," IEEE Computer it Vision and Pattern Recognition Computer Society Conference on, 592-598, June 1991.

[7] David Nister, "A Minimal Solution to the Generalized 3-Point Pose Problem," IEEE CVPR, 2004.

[8] Dimitrios Karagiannis, Alessandro Astolfi, "A New Solution to the Problem of Range Identification in Perspective Vision Systems," *IEEE Transactions on Automatic Control,* vol. 50, NO. 12, December 2005.